Title: Radiated Energy and State of Stress During Earthquake Rupture

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Program Element: Research on Earthquake Occurrence and Effects

Investigation undertaken

We determined the radiated energy from regional data for the M_w 7.1 Hector Mine, California, earthquake. The Hector Mine earthquake and its aftershocks were well recorded at 67 TriNet stations in southern California. The good signal-to-noise ratio of the main shock and several aftershocks enabled the use of the empirical Green's function method to determine the source time function from which the radiated energy can be computed accurately. We compared the energy thus determined with that estimated from teleseismic data.

Results

The Hector Mine earthquake and its aftershocks occurred within the dense array of TriNet stations in southern California. The aftershocks were used as empirical Green's functions. The main shock velocity record was obtained by integrating the original acceleration record.

To determine the source time function, we selected five events (one pre-shock and four aftershocks with $M_w \sim 2.8\text{-}4.5$) located close to the hypocenter of the main shock. We used the seismograms of these events as empirical Green's functions (EGF). We deconvolved the main shock record using the EGF records to remove the path and site effects from the main shock record. Of the five EGFs, two aftershocks (origin times October 16, 2000, 2253 UT and October 19, 2000, 1220 UT) have mechanisms that are most similar to the main shock and are located close to the fault trace. The deconvolution worked best when these two aftershocks were used as the EGF events.

The radiated energy can be calculated from the source spectrum using the relation:

$$E_s = \frac{1}{10\pi^2 \rho \beta^5} \int_0^\infty \omega^2 \dot{M}^2(\omega) d\omega$$

where ρ is the density at the source, β is the S wave velocity in the source region, and $\dot{M}(\omega)$ is the source spectrum. The integration extends from $\omega = 0$ to ∞. However, since the signal-to-noise ratio at frequencies above 1 Hz and below 0.05 Hz is poor, the integration is carried out only over this frequency range. The contribution from outside of this frequency band is estimated using a theoretical spectrum.

The energy is calculated using $\rho = 2.7\text{g/cm}^3$, $\beta = 3.3$ km/s for each depth of the EGF. We also used screening criteria where we excluded stations at distances greater than 200km from the main shock and stations located close to the radiation node of either the main shock or the aftershocks. We estimated the energy for each station. The energy values estimated for each station are tightly clustered between $2\text{x}10^{22}$ and $4\text{x}10^{22}$ ergs.

The teleseismic data for the Hector Mine earthquake were obtained from the IRIS Data Management Center. We used the vertical component data (BHZ channel) of stations between 30° and 90° in the teleseismic study. We computed teleseismic energy using two methods. The first method is the conventional method where the energy is computed by applying corrections to the integrated velocity spectrum (Boatwright and Choy, 1986). The moment rate spectrum is determined using:

$$\dot{M}(\omega) = \frac{4\pi\rho\alpha^3 R_E e^{(\omega t^*/2)} u(\omega)}{g(\Delta) R(\theta, \Phi) I}$$

where $\dot{M}(\omega)$ is the source spectrum, ρ is the density at the source, α is the P wave velocity at the source, $u(\omega)$ is the displacement spectrum, R_E is the radius of the earth (= 6371 km), t^* is the attenuation constant (travel time divided by the path average Q), $g(\Delta)$ is the geometric spreading factor, I is the instrument response and $R(\theta, \Phi)$ is the effective

radiation pattern for the P wave group. $R(\theta, \Phi)$ is obtained by computing the amplitudes of the P, pP and sP phases at each station and then taking the root-mean-square value. We use a frequency dependent t^* model slightly modified from that given by given by Der (1998).

In the second method we compute Green's functions for an appropriate near source structure using the method of Kikuchi and Kanamori (1991) and deconvolve the main shock data to obtain the source spectrum at each station.

The first method underestimates the moment slightly and results in energy values between 0.4×10^{22} ergs and 10×10^{22} ergs with a median of 2×10^{22} ergs. The second method results in energy values between 1×10^{22} ergs and 10×10^{22} ergs with a median of 5×10^{22} ergs.

The Hector Mine earthquake is unique in that both the main shock and aftershock data are well recorded and hence we can use an empirical Green's function method to determine the source time function and compute energy from the source spectrum. The teleseismic estimates obtained from both methods are less reliable than the regional estimates because of the uncertainties in the attenuation, source site response, and directivity.

From the regional estimates of radiated energy ($2\text{-}4 \times 10^{22}$ ergs) and teleseismic inversions for the moment (6×10^{26} dyne-cm), the energy to moment ratio for the Hector Mine earthquake is between 3×10^{-5} and 6×10^{-5}.

References

Boatwright, J. and Choy, G. L., Teleseismic estimates of energy radiated by shallow earthquakes, *J. Geophys. Res., 91*(B2), 2095-2112, 1986.
Der, Z. A., High frequency $P\_$ and $S\_$ wave attenuation in the earth, *Pure and Applied Geophysics, 153,* 272-310, 1998.
Kikuchi, M. and Kanamori, H., Inversion of complex body waves-III, *Bull. Seismol. Soc. Am., 81*(6), 2335-2350, 1991.

Non-technical Summary

The energy radiated from an earthquake provides key information regarding how the earthquake occurs and what kind of ground motion would result from it. Unfortunately, it is very difficult to estimate the energy accurately, because seismic waves generated from an earthquake propagate in a complex structure of Earth's crust. For the 1999 Hector Mine, California, earthquake (Mw=7.1), very high-quality data were obtained from the newly installed TriNet seismic network. We could determine the total amount of energy radiated from this earthquake accurately. The energy estimated is 2 to 4×10^{15} Joules. This result is important for understanding the basic physics of earthquakes.

Reports

Kanamori, H. and T. Heaton, Microscopic and Macroscopic Physics of Earthquakes, *GeoComplexity and the Physics of Earthquakes*, *AGU Monograph Series 120*, 147-163, 2000.

Venkataraman, A., J. Mori, and H. Kanamori, Fine Structure of the Rupture Zone of the April 26 and 27, 1997, Northridge aftershocks, *J. Geophys. Res., 105*, 19,085-19,093, 2000.

Kanamori, H. and J Mori, Microscopic processes on a fault plane and their implications for earthquake dynamics, *Problems in Geophysics for the New Millennium*, Eds. E. Boschi, G. Ekström and A. Morelli, - Proceedings Erice 1999 - , Editrice Compositori for Istituto Nazionale di Geofisica, Roma, in press.

Brodsky, E. and H. Kanamori, The Elastohydrodynamic Lubrication of Faults, *J. Geophys. Res.*, submitted.

Data availability

All the data used in this research are available from the Data Management Center of IRIS, and the Data Center of Southern California Earthquake Center.